University of Manitoba

First Measurement of the 7s-8s M1 Transition in Francium

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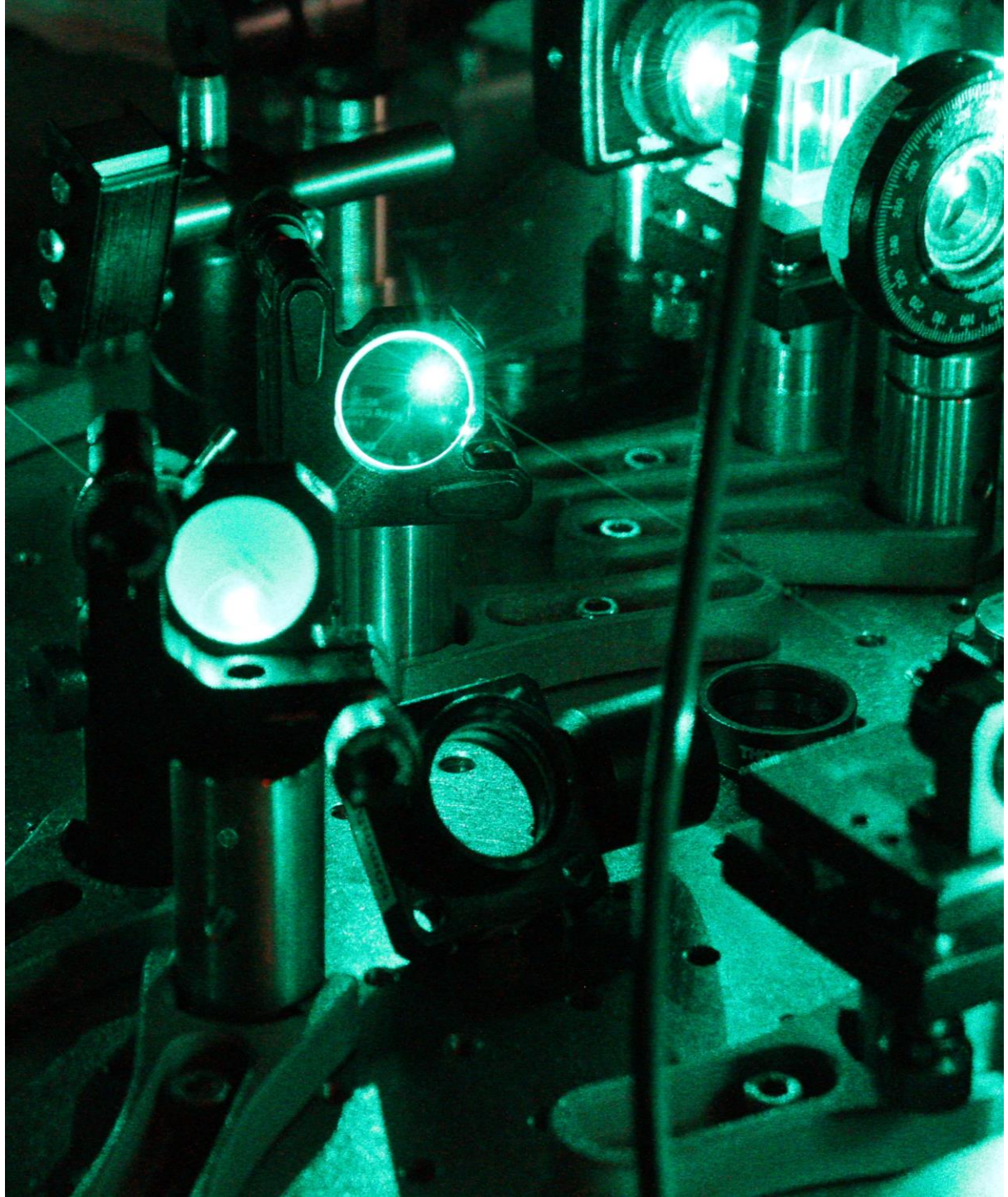
CAP 2022



Faculty of Science
Department of Physics and Astronomy

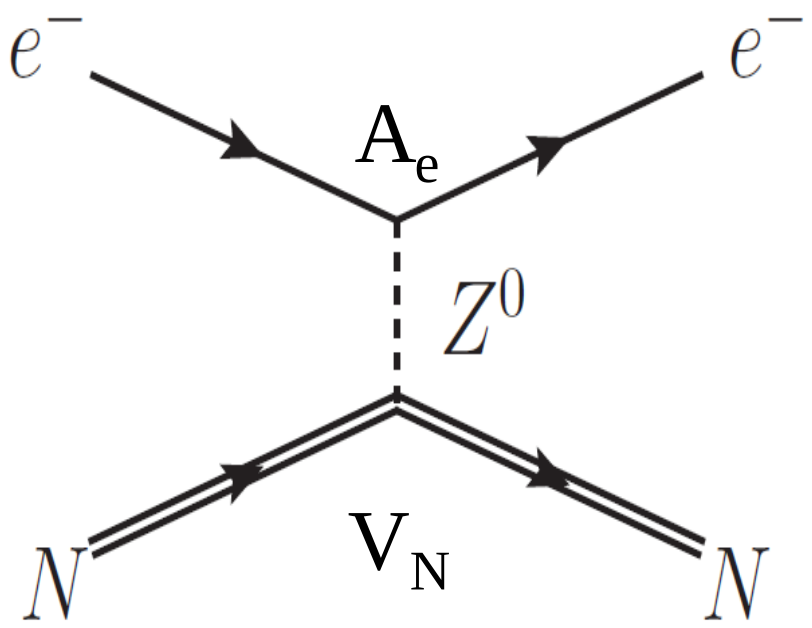
2022-06-08

Atomic Parity-Violation (APV) in Francium

- Study APV in Fr at TRIUMF
- Z-boson exchange between atomic electrons and quarks in the nucleus
- APV scaling ~Z^2N
- Francium ideal candidate for APV measurement
- Excite 7s-8s transition in an external electric field:
- $R_{7s-8s} \propto |A_{Stark} + A_{M1} + A_{PV}|^2$

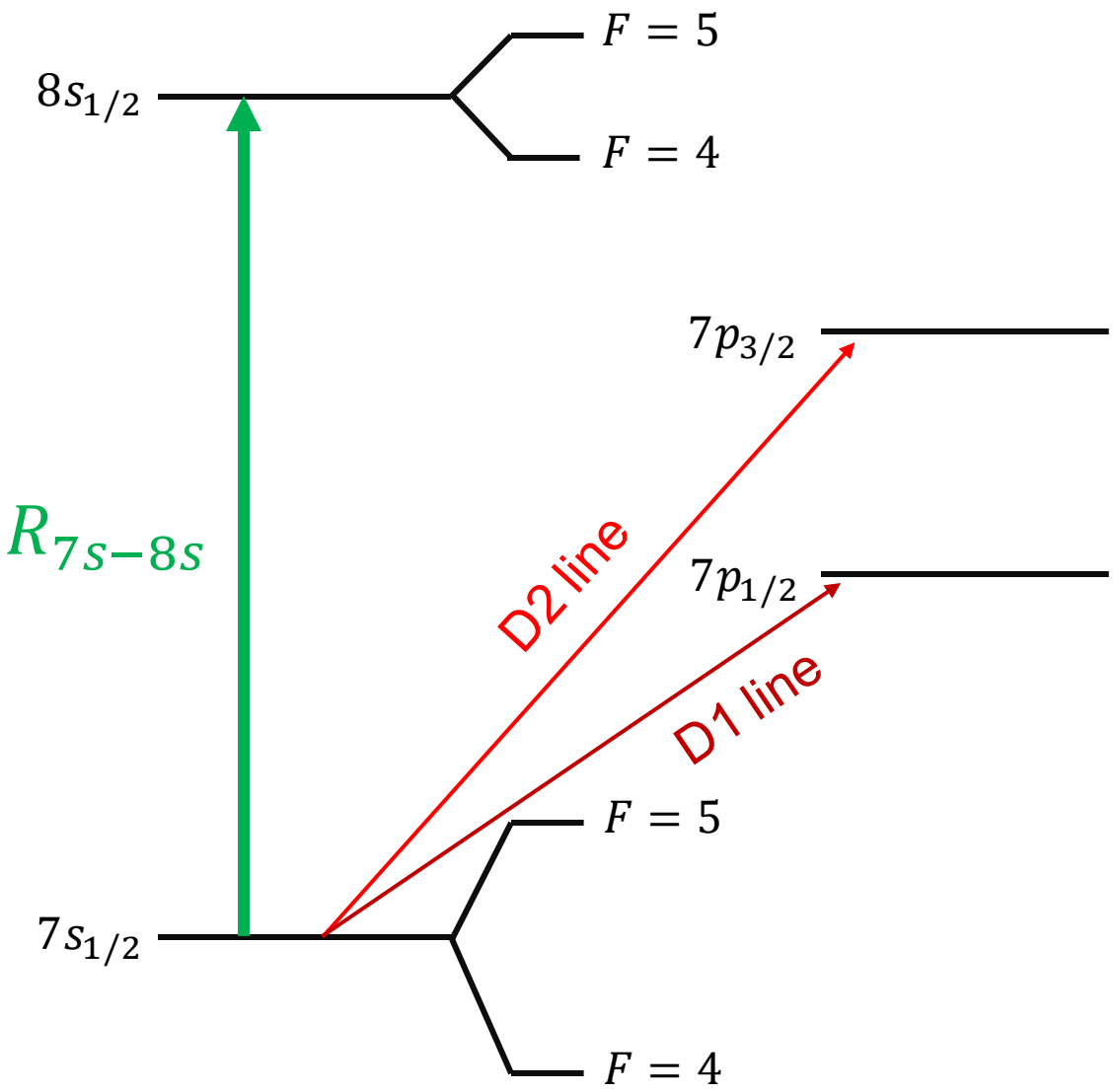
Interference between amplitudes used for APV experiment

Small magnetic dipole (M1) transition present.
This is what we observed!



Nuclear Spin Independent (NSI) APV, dominant in heavy atoms

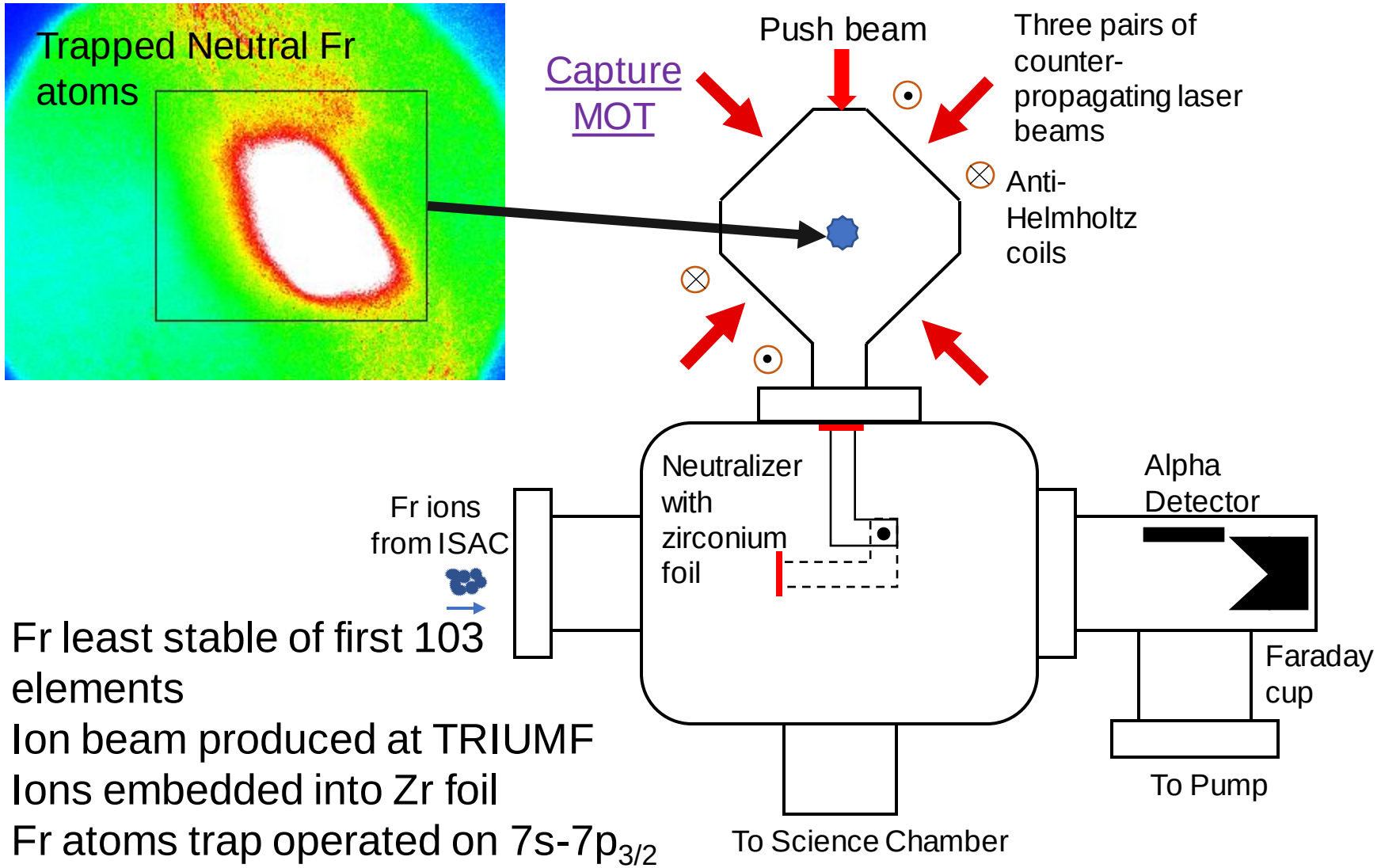
Magnetic Dipole Transition (M1)



- 7s-8s transition → magnetic dipole forbidden
- State mixing due to relativistic effects and hyperfine interaction → M1 appears

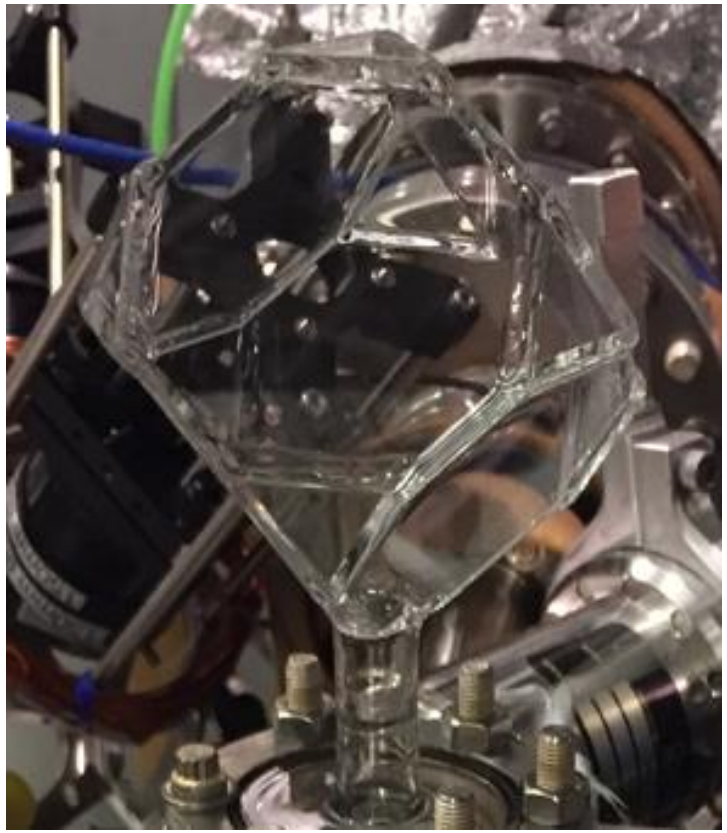
- Fr 7s-8s M1 osc. strength $f \approx 10^{-13}$
- Neglecting A_{PV}, transition rate:
- $R_{7s-8s} \propto |A_{Stark} + A_{M1}|^2$
- $A_{Stark} \propto \beta E$
- $A_{M1} \propto M = M_{rel} \mp M_{hf}\delta_{F,F\pm1}$
- Need M/β ratio for APV
- Test M_{rel} and β against atomic calculations

Experimental Setup: 1. Capture Chamber

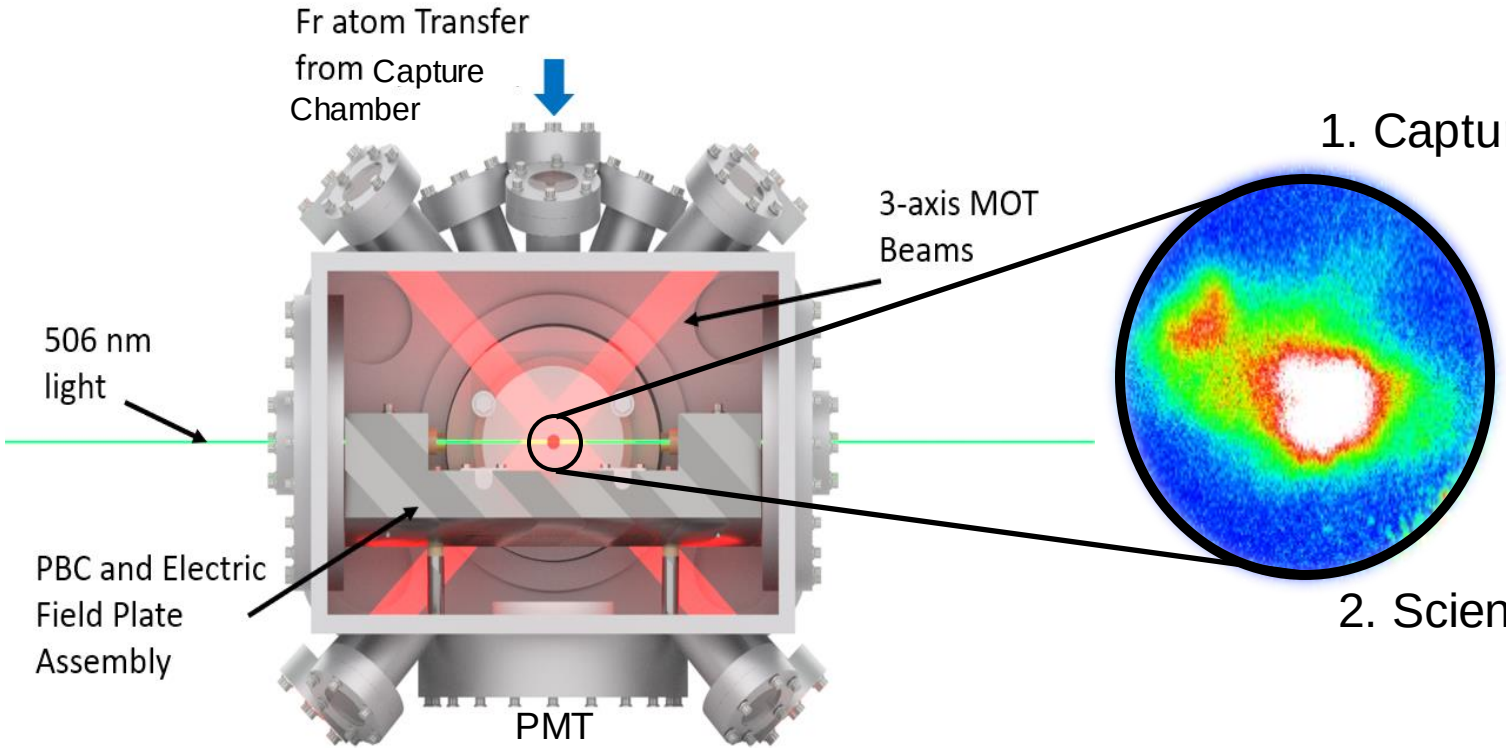


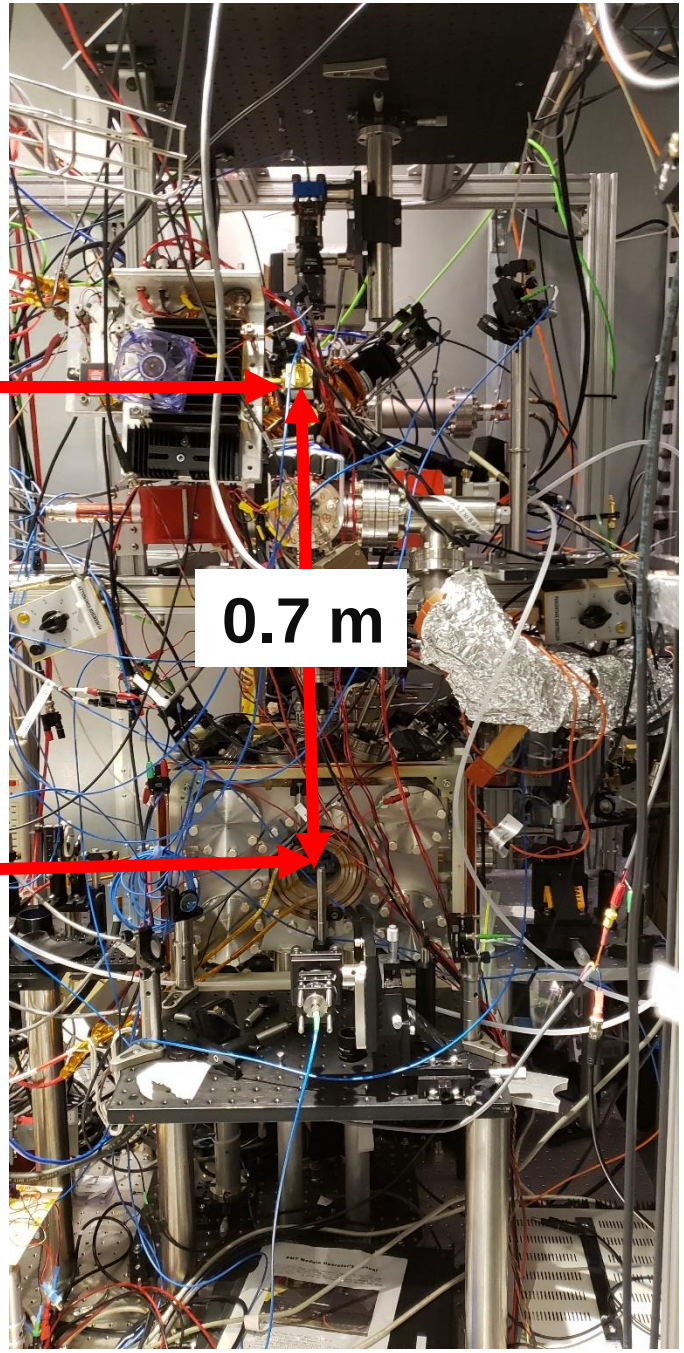
- Fr least stable of first 103 elements
- Ion beam produced at TRIUMF
- Ions embedded into Zr foil
- Fr atoms trap operated on $7s\text{-}7p_{3/2}$ (D2) transition
- Trap ~10^5 atoms

Coated glass cell



2. Science Chamber

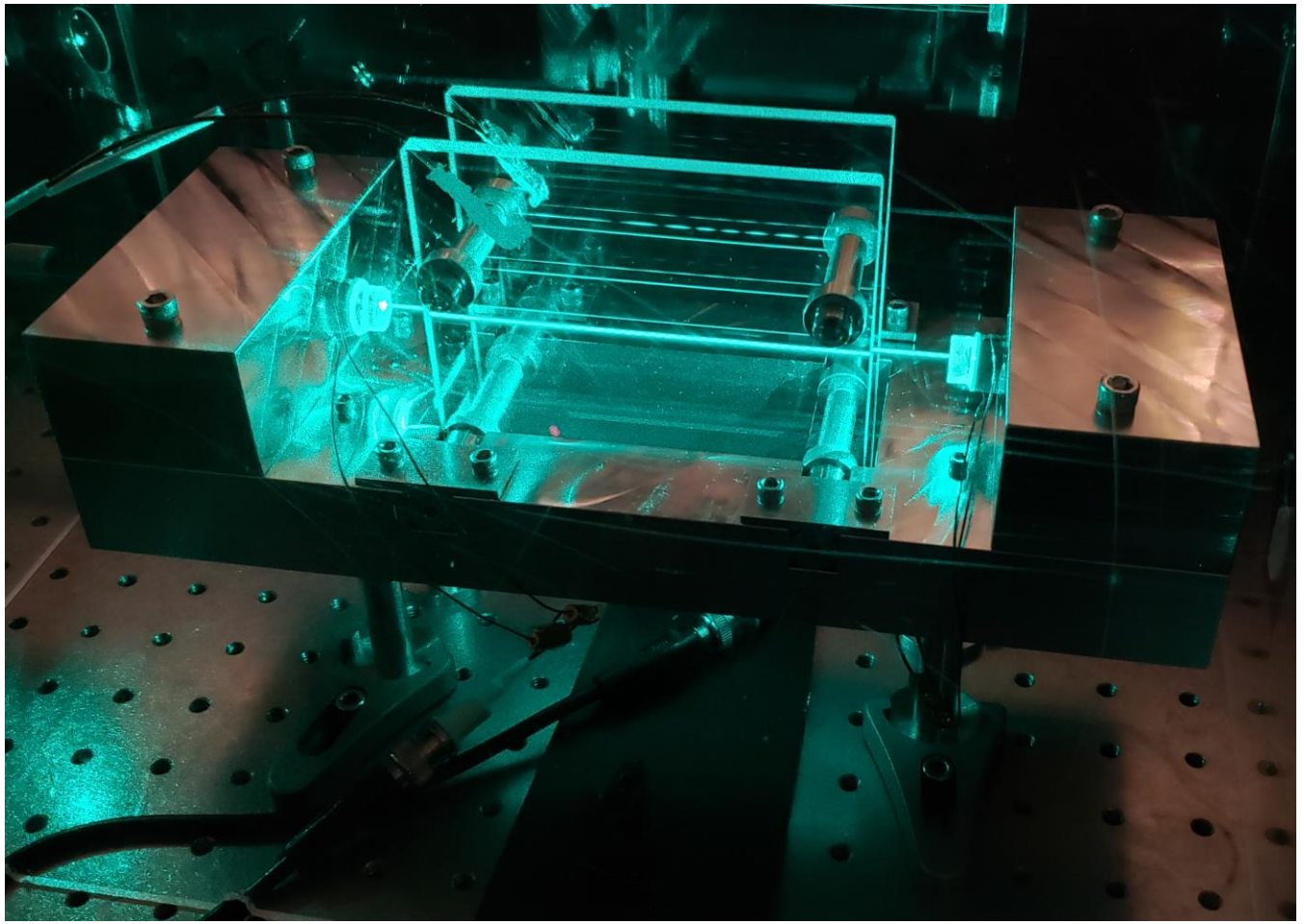




- Atoms transferred to secondary chamber (Science chamber)
- ~ 50% atom transfer efficiency
- Re-trap and prepare atoms for spectroscopy
- Science chamber features electric field plates and new power buildup cavity (PBC)

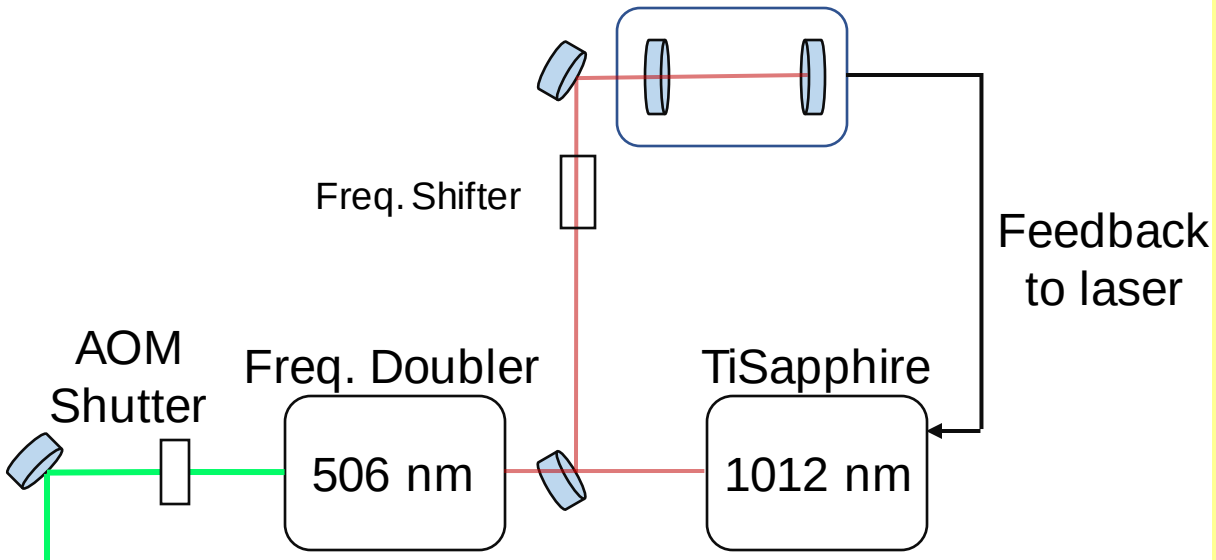
Power Buildup Cavity and Field Plates

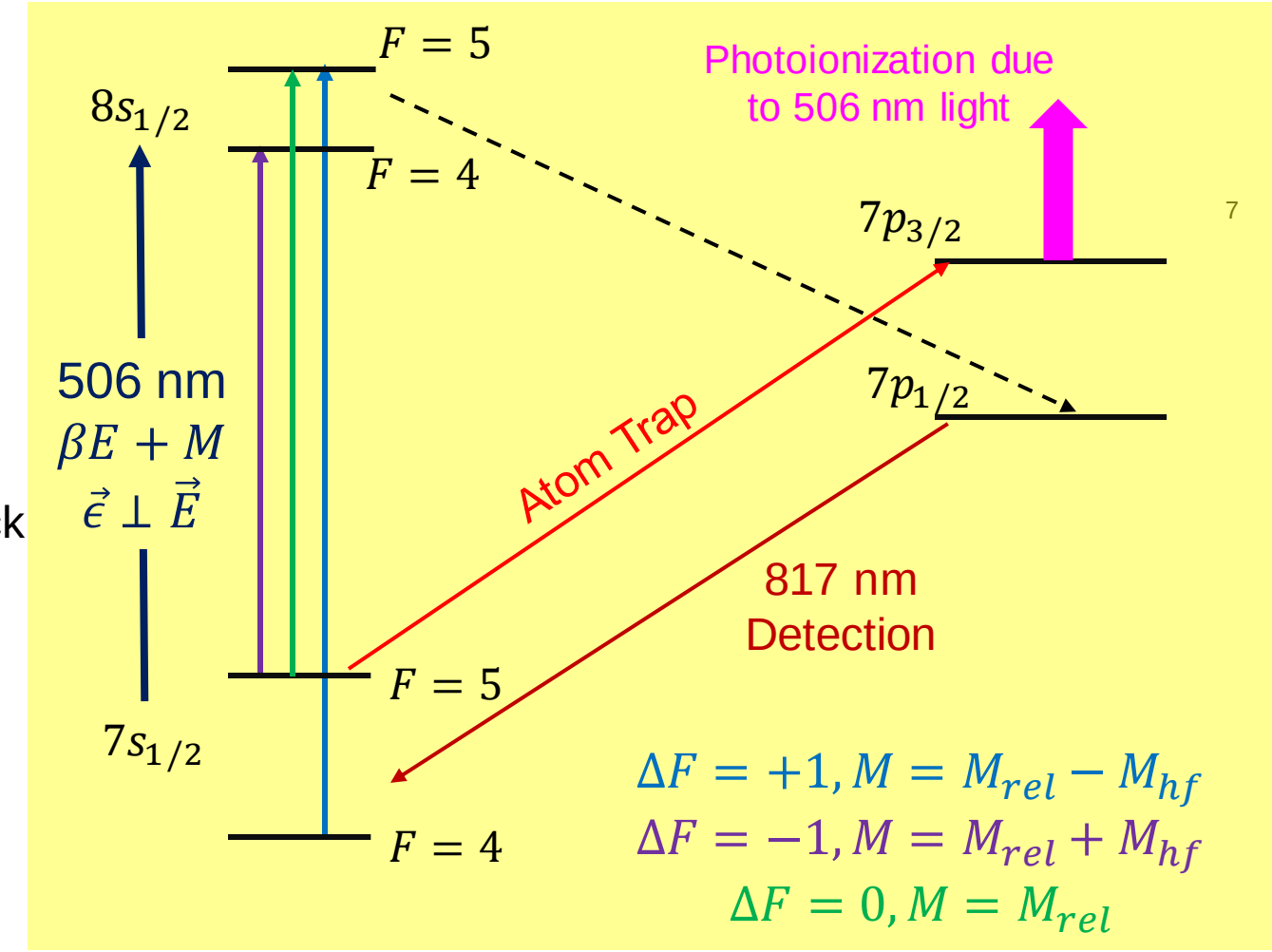
- UHV-compatible PBC (~4000x)
- Piezos controlled using PID feedback to keep length fixed
  - Pound-Drever-Hall locking technique
- Transparent ITO coated electric field plates sit atop PBC base
  - Plate spacing: d = 2.858 ± 0.003 cm
  - Plates are connected to high voltage power supplies
- PBC suppresses $A_{Stark}A_{M1}$ interference

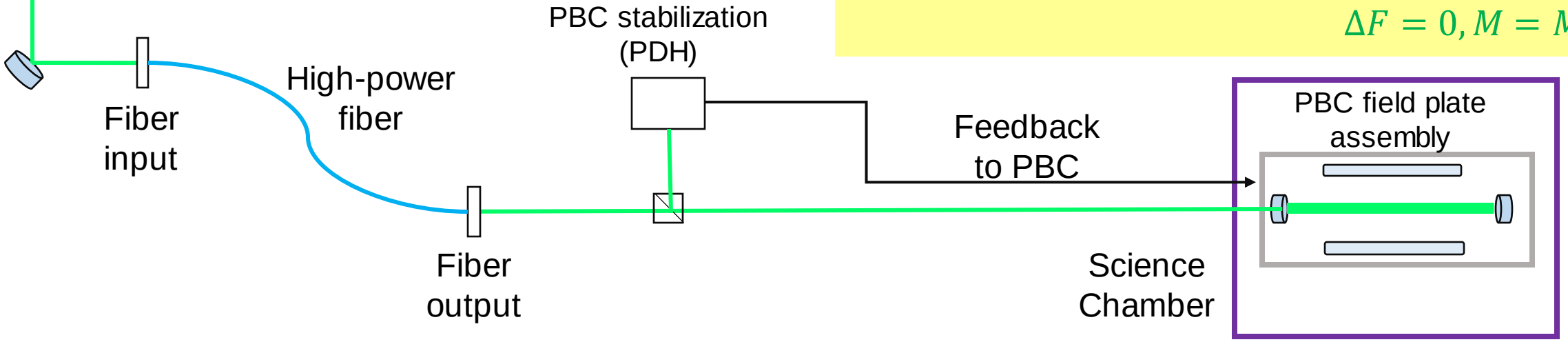


Laser Spectroscopy

ULE based laser freq. stabilization (PDH) (10^{-10} stability)

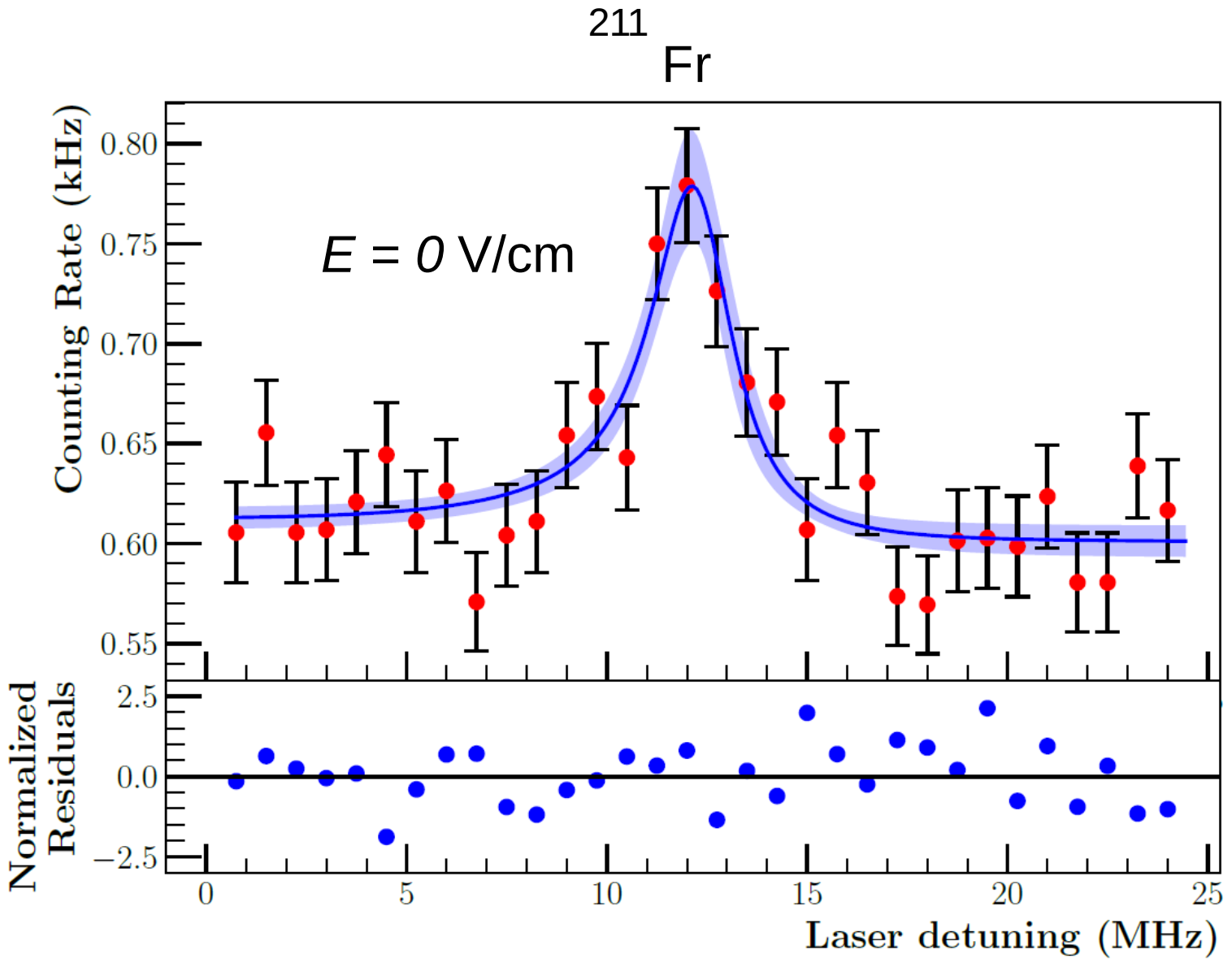






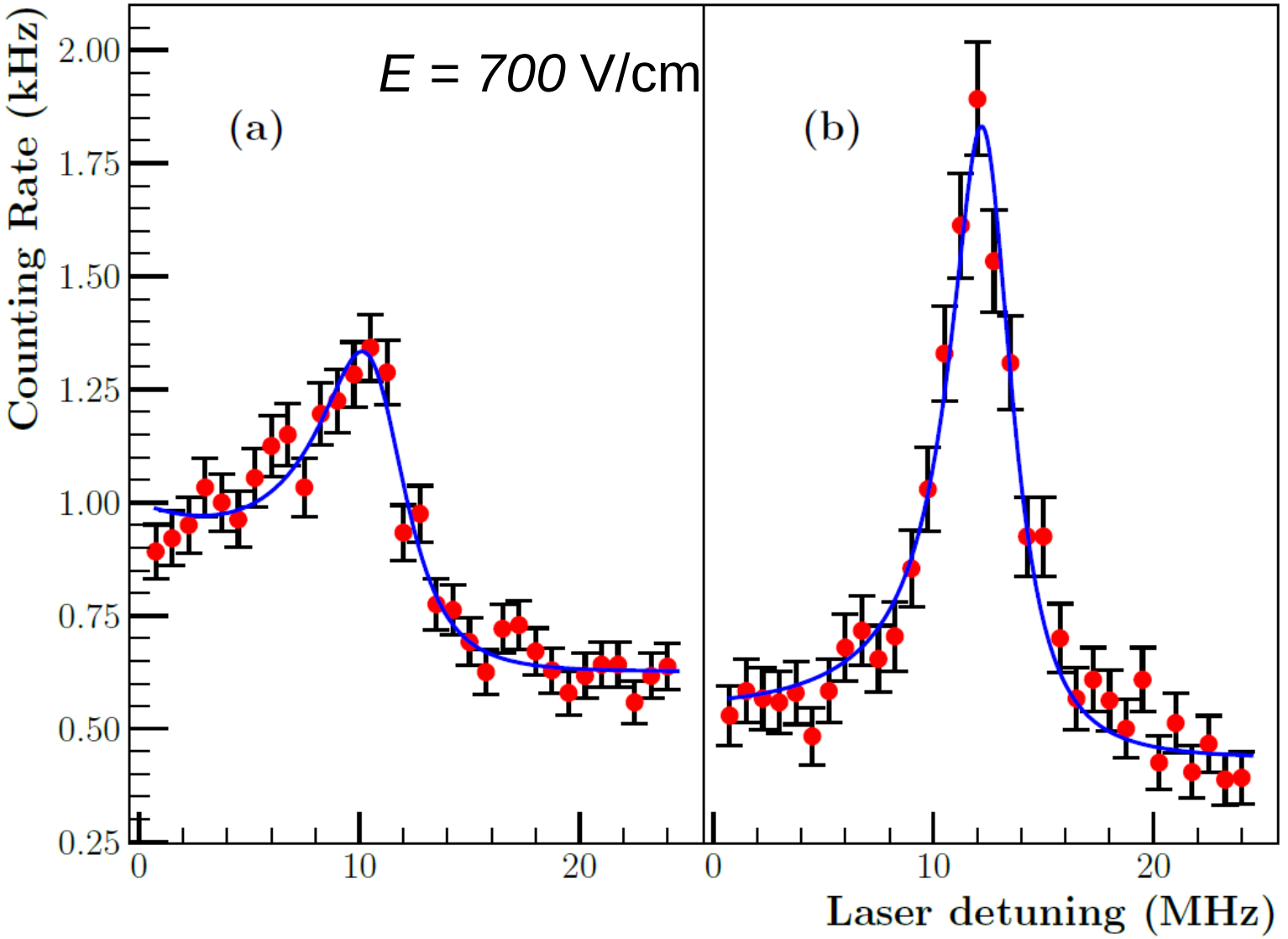
M1 Spectrum

- Excite ΔF=-1 at various electric fields E
- Spectra averaged over 10-30 scans
- Determine area from fit
  - Function: Exponential decaying Lorentzian
- Normalize Transition rate
  - atom number
  - laser power
- M1 transition directly observed



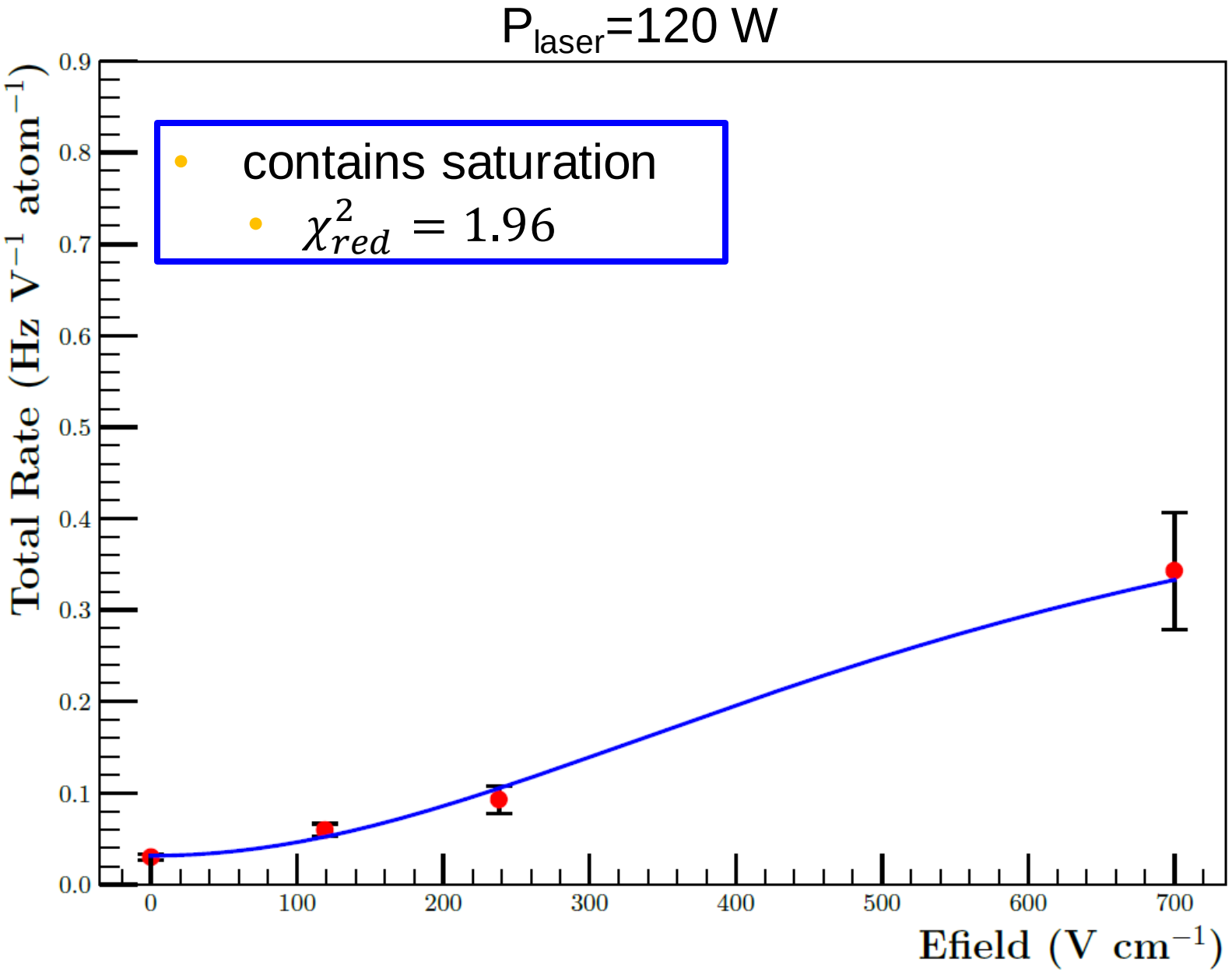
Saturation from Hyperfine pumping

- Observed saturation of the transition
- (a) Highly saturated at 100% laser power
  - 100% ≈ 120 W within PBC
- (b) Reduced laser power to 19%(~23 W)

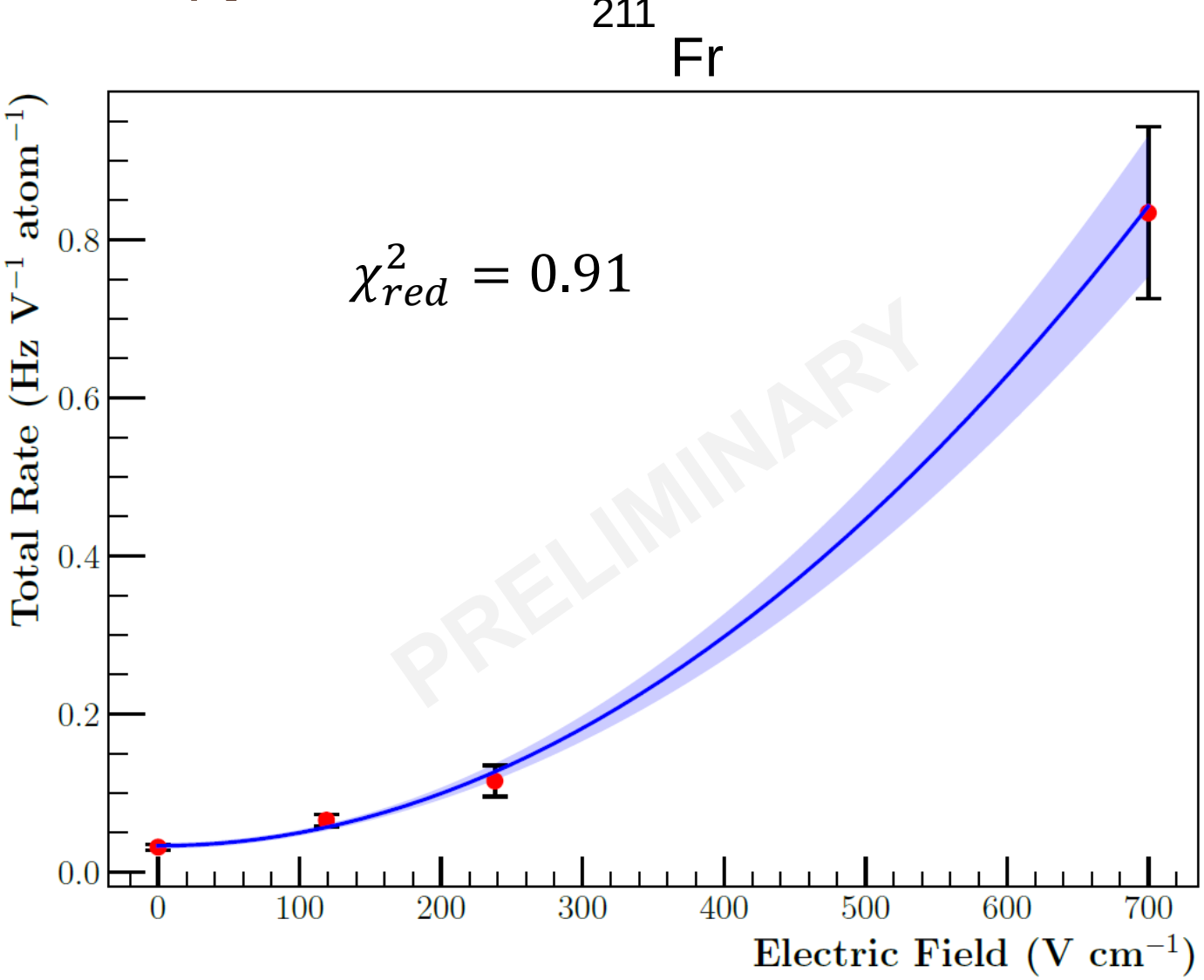


Saturation

- Determine saturation rate from plot
- Cross-checked saturation with linewidths of our spectra
  - Agreement within uncertainty
- Factor out saturation
  - Average data at same E field but different laser power



M/β Result



Theory Calculations for M_{rel} ($\times 10^{-5}$ μ_B)

[1]

Z	Li 3	Na 11	K 19	Rb 37	Cs 55	Fr 87
I	0.91	1.16	1.15	1.38	1.51	2.09
II, *no-pair*	0.12	0.03	-0.08	-1.86	-10.69	-116
II, NES	0.02	0.13	0.20	0.31	0.40	0.64
Total	1.05	1.06	1.27	-0.17	-8.78	-113

[2]

		Tran	DF	DF [16]	RPA	RPA [16]	MBPT3
Fr	NBr	$8s-7s$	-2.559		177.1		139.9
	Br	$8s-7s$	-3.000	-2.49	174.4	176.5	137.4

[1] Savukov *et al. Phys. Rev. Lett.* 83, 2914, 1999 (table I)
[2] Safronova *et al. Phys. Rev. A* 95, 042507, 2017(table VI)
β taken from Safronova *et al. Phys. Rev. A* 60, 4476,1999 (table IX)

- $|M/\beta| = 143 \pm 11$ V/cm
- $|M_{rel}| = 130 \pm 10 \times 10^{-5}$ μ_B
- Goals for August 2022:
  - Improve $|M/\beta|$
  - Extract $|M_{hf}/\beta| \rightarrow \beta$

Conclusion

- Excite 7s-8s transition in trapped francium
  - Single photon at 506 nm
- APV measurement requires knowledge of M1
- Measured M/β along $\Delta F=-1$ hyperfine transition
- Determined M_{rel} form M/β

Thank you.

Collaboration:

University of Manitoba:
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